Towards Developing Effective Continence Management through Wetness Alert Diaper:

Experiences, Lessons Learned, Challenges and Future Directions

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Abstract— **Incontinence is one of the major healthcare issues in everyday nursing care especially for frail elderly and patients with dementia (PWD) in nursing homes. Urinary incontinence and diaper use are prevalent in PWD due to decline in intellect and physical activities. They may lie in soiled diapers for prolonged periods resulting in indignity, discomfort, skin breakdowns and bedsores. In order to alleviate this, we propose a solution using wetness alert diaper capable of timely diaper change. In this paper, the experiences and lessons learned from initial evaluation trials with intelligent Continence Management System (iCMSv1) are explained. Then, desirable refinements and extensions are made to develop iCMSv2 enabling anywhere anytime continence management. We finally discuss challenges and possible future directions towards developing a new care model to manage incontinence effectively and efficiently.**

Keywords-urinary incontinence; patients with dementia; continence management; wetness alert diaper

I. INTRODUCTION

Incontinence, either urinary or fecal, is not a normal part of ageing and is a sign of serious problem causing social, personal and economic setbacks [1]. Elderly especially PWD who may not control the release of urine or bowel suffer from incontinence related problems [2]. Urinary incontinence, highly prevalent in PWD [3], is one of the leading daily nursing care problems around the world [1]. The incontinence problems do not only relate to patients who suffer but also affect the primary carers [4]. Tan et al [5] studied clinically on how to maintain desirable continence levels for dementia patients. Various assessment and treatments available to the incontinent patients are reported in [6][7]. The evaluation of various incontinent products and devices available in the markets has been done in [8], but none of those products found viable solution to manage incontinence. A non-technical method, behavioral intervention, [9] proved its usefulness in normal (not for PWD) nursing home population. According to our knowledge, there is still lacking for an accessible assistive solution for carers in managing incontinence among PWD in nursing homes.

Usually, PWD with irreversible incontinence factors have to wear diaper all the time to avoid potential medical and social implications. But timely diaper change is needed to avert the problems of staying in soiled diapers. They usually do not have self ability to notice and notify the carers of being incontinent. Ideally, carers must know who is incontinent and attend to PWD with soiled diaper without delays. But incontinence episodes can occur at anytime; there is no fixed or regular timing. This requires carers to check diaper wetness from one patient to another and to perform these scheduled diaper checks at every specified interval. This approach is time consuming, labor intensive and causing annoyances to the patients as well as carers. So it is not feasible and effective to provide round the clock care to multiple incontinent patients in nursing homes. This demands the use of pervasive solution assisting carers by notifying incidence of incontinence episodes of the patients in order to provide desirable level of continence management.

The focus of this paper is to present our works on developing a solution for effective continence management through wetness alert diaper. The experiences and lessons learned with iCMSv1 from initial clinical trial are discussed. Subsequently, iCMSv2 is designed and developed to support the desirable features and address the limitations observed from iCMSv1. Finally, challenges and possible future directions are explored aiming towards developing effective and efficient continence management.

II. RELATED WORKS

There are several commercial enuresis products and research prototypes aiming to solve the ailments related to incontinence problems [10]. The use of wearable urine collector was developed to solve the problems of incontinence in female patients [11]. But the use of this device is quite obtrusive as the patient requires carrying a tube to store urine. Our approach is applicable to any gender by wearing normal diaper that is embedded with small unobtrusive wetness sensor inside. There are also similar works using wireless sensor network and RFID based sensing technology to monitor incontinence [12][13]. The main limitation with their work is that coverage and wireless range for RFID is severely limited compared with the sensor used in our solution (DRI-Sleeper Eclipse model, AnzAcare Ltd, New Zealand). So, carer is still required to check diaper wetness from one patient to another. In practical care settings, least carer involvement is desirable such as prompting carers automatically as soon as soiled diaper is detected.

As of now, there are still limited studies with enabling technologies on providing continence management for PWD. So we are aiming to address this gap examining how our approach can assist carers in managing incontinence. We will also conduct clinical trials to validate applicability of our approach in timely diaper change without requiring much carers' attention. We believe that this can lead to a new care delivery model for continence management of PWD.

III. CONTINENCE MANAGEMENT TRHOUGH WETNESS ALERT DIAPERS

There are various levels of handling incontinent patients starting from assistive toileting, time voiding to medications and surgeries depending on the needs of the patient. The most basic handling of incontinence includes managing incontinence such as assistive toileting and using diapers.

A. *Objectives and Hypotheses*

The main engineering goal of iCMS is to develop an effective continence management solution through wetness alert diaper using enabling technologies such as sensors, sensor network [14], ambient intelligence[15] and context-aware in-situ reminders [16][19]. The objective from clinical perspective is to promote timely diaper replacement without requiring extra carers' resources and maintaining desirable level of continence at the same time. The main hypothesis is that timely diaper replacement can be achieved with iCMS, avoiding unnecessary scheduled diaper check, without having soiled diapers. Without such a solution, patients may lie in soiled diaper without carer's timely attendance although regular scheduled manual diaper check is performed.

B. *Requirement Analysis and Evaluation Study*

Initially, requirement analysis studies are performed [17] to understand the problems, needs, and practices related to incontinence. Then, evaluation of existing technologies and products have been carried out to select appropriate enabling technologies according to actual clinical requirements [17][18]. After having discussion with doctors, nurses and carers from local nursing home, we realized that majority of elderly residents totally depend on carers for maintaining desirable level of continence. According to trial evaluation plan, a group of incontinent patients have to be recruited to assess how iCMS is effective and useful in managing multiple incontinent patients with a small group of carers. Currently, the scheduled diaper check is done on the average of five times a day at specified times [18] but no bladder charting is done. Based on existing clinical practices, requirements and research criteria, architecture, software components and trial study design of iCMS will be explained and discussed in subsequent sections.

C. *System Architecture*

Based on initial requirement and feasibility analysis [17][18], the architecture of iCMS can be designed as shown in Fig. 1. It consists of three sub-systems: sensing, networking and intelligence. In this architecture, only the technical and functional requirements are considered. The clinical usability and acceptability requirements are not covered.

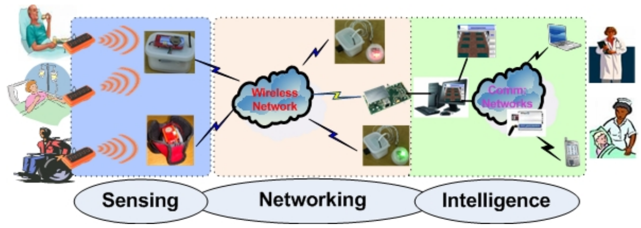

Figure 1. Overview of 3-Tier System Architecture of iCMS

The sensing sub-system supports timely detection of diaper wetness events using wetness sensor unobtrusively and non-invasively. The networking sub-system based on pervasive wireless sensor network platform (micaZ mote, Crossbow Inc, San Jose, CA, USA) provides scalable and distributed monitoring as well as extended coverage of incontinence episode observation. The intelligence sub-system controls the whole system operations and provides context-aware in-situ alerts for notifying carers of soiled diapers. Thus, iCMS assists carers, enabling timely diaper change via prompt detection of wetness episodes through sensors, anywhere anytime.

D. *System Overview, Operations & Evaluation Scenarios*

The Fig. 2 illustrates how iCMS is developed with different top-level functional software system components according to a 3-tier system architecture.. The sensing and networking sub-systems are implemented as diaper sensor network consisting of sensing nodes, relay/alert nodes and gateway node [18]. The intelligent sub-system is developed adopting web-based service oriented approach to be easily managed, accessible and extensible.

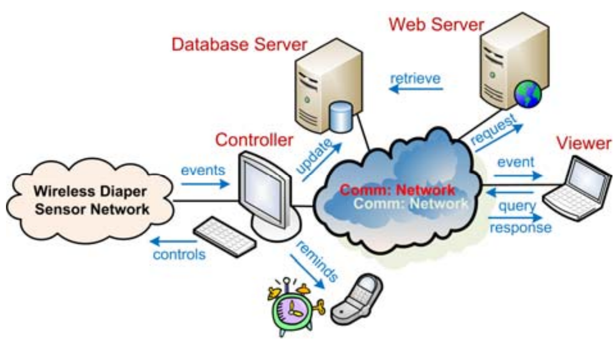

Figure 2. Overview of iCMS Functional Software Components

The general system operation flow is also depicted in Fig 2. When the diaper is soiled, sensor embedded in the diaper emits an event signal. That signal is relayed wirelessly through diaper sensor network to the "**Controller**" for processing. As soon as the "**Controller**" recognizes detected wetness events, a reminder is subsequently sent to carers through different alerts, for timely diaper change. All information and transactions are recorded through the "**Database Server**" for data analysis and retrieval. The "**Web Server**" serves a website that enables seamless control of iCMS operations as well as online and offline access of incontinence profiles of particular patient through the "**Viewer**". In order to validate effectiveness and to evaluate usefulness of iCMS, clinical evaluation trials with iCMS on real patients must be conducted. The evaluation study, design methodology and trial protocols are defined as shown in Fig. 3. The effectiveness of detecting soiled diapers with iCMS will be validated by comparing with the actual cases of diaper wetness.

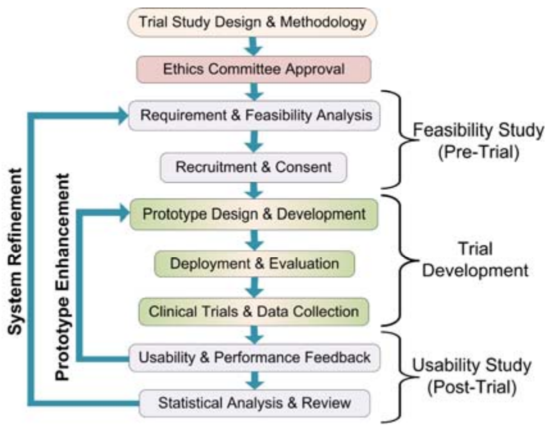

Figure 3. Evaluation design and methodologies for iCMS

IV. INITIAL SYSTEM IMPLEMENTATION: ICMSV1

After evaluating various technologies with respect to desirable technical and clinical requirements for managing incontinence, initial hardware and software modules for iCMSv1 are designed and developed as shown in Fig. 4.

A. *System Overview & Development*

iCMSv1 consists of four main components: Wetness Alert Diaper (WAD), Wetness Events Alarms (WEA), Wetness Events Visualizer (WEV), Management & Database Server (MDS), as shown in Fig. 4. It also mentions how users can relate to and interact with these system components.

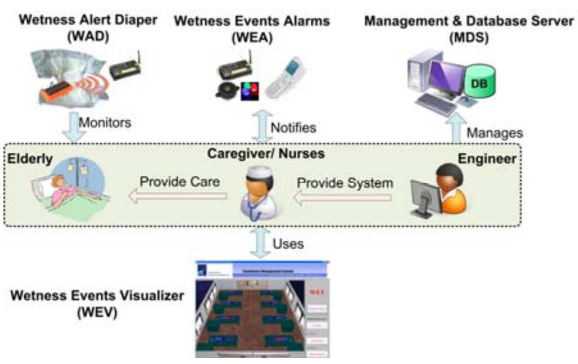

Figure 4. Overview of iCMSv1 Components and Interactions

WAD, the sensing node, monitors elderly incontinence status and generates events upon detecting diaper's wetness. WEA, the alert/relay node, alerts carers through in-situ reminders when soiled diaper is detected. Carer(s) manages iCMSv1 operations through WEV. MDS manages whole system operations and logs the events and states occurred relevant to incontinence episodes and care giving operations.

B. *System Deployment & Clinical Study*

After successfully testing out technical functionalities at the lab, clinical trial with single PWD was conducted at nursing home by deploying iCMSv1 as shown in Fig. 5. Details of iCMSv1 deployment and trial operations can be found in [20]. The focus of the study is on evaluating technical functionalities under actual care settings and there is less emphasis on clinical aspects. During the trial, manual incontinence care is provided in parallel with iCMSv1. Along with logging done by iCMSv1, manual bladder charting is recorded as ground truth to evaluate effectiveness of iCMSv1 in detecting soiled diaper.

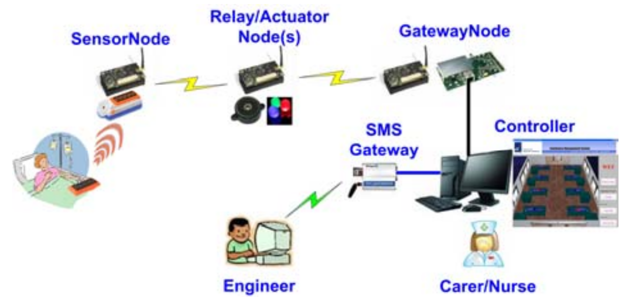

Figure 5. iCMSv1 Nursing Home Deployment Configuration

V. EXPERIENCES AND LESSONS LEARNED FROM INITIAL CLINICAL TRIAL WITH ICMSV1

In this pilot study, the unpredicted technical, clinical and operational issues can be observed with iCMSv1 under real nursing home environment. From trial outcomes and day to day observations, we gained invaluable experiences and learned lessons to develop desirable continence management solution.

A. *Trial Results and Achievements*

The post-trial analysis was performed comparing manually-recorded bladder charting ground truth with iCMSv1 logged incontinence episodes. From this analysis, iCMS-v1 showed modest sensitivity (56%) and high specificity (100%) in detecting soiled diapers. The sensitivity was compromised due to wrong sensor positioning, human operation errors and technical limitations. Wrong sensor positioning can be avoided by ensuring proper sensor placement. Reasons for the ineffectiveness of the initial trial included technical limitations such as reusability of wetness sensors and once-only "catch or miss" type of signal transmission upon the detection of wetness episode. Other reasons for the ineffectiveness of the trial are human operation errors such as improper sensor placement and incorrect operation sequence. Although there is only detection on half of actual incontinence episodes, the whole system can run smoothly, without serious technical problems, and there is no down-time throughout the trial.

According to Fig. 6, unnecessary manual diaper check, 52% excess, was performed but less detection, 53% less, from system compared with actual diaper replacement. This means both manual and automated interventions with iCMSv1 are ineffective. On the other hand, manual scheduled checks only performed 48.15% of total possible manual scheduled checks over trial duration. This shows inefficiency of scheduled diaper checks although only half of diaper checks are carried out but more than 50% of these checks were unnecessary.

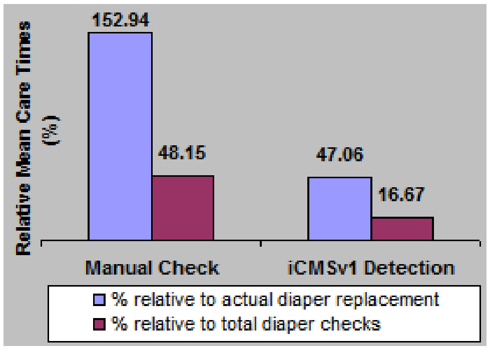

Figure 6. Statistics of manual diaper check and iCMSv1 events

Although the this trial outcome does not prove that iCMS can enable effective continence management for PWD, this pilot study provides invaluable lessons and experiences in determining desirable features and functionalities of iCMS.

B. Lessons learned from Clinical Trial

Although the average numbers of carers during day time is approximately 4 times more that that of night time, there is not much difference between mean manual day and night care, which are 42.4% and 54.5% respectively. Sometimes night time care was carried out more often than day time care, as shown in Fig. 7. But, only manual care attendance of 47.3% was achieved during the trial. So the quality of care cannot only be affected by carers availability and time of the day but also on other parameters such as number of patients to attend to, etc. This means manual diaper check is not feasible and difficult to adhere and ineffective in long-term care settings.

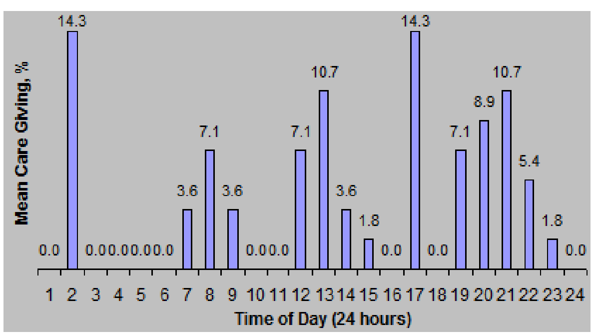

Figure 7. Statistics of Mean Care Giving with Respect to Time of Day

From Fig. 8, the statistics of comparing actual manual diaper checks with total manual diaper checks according to scheduled interval [20] can be clearly seen. This provides an understanding that manual care has difficulty in providing timely attention to the patients according to scheduled diaper checks. As mentioned in Fig. 9, the missing percentages such as 19% at 8:00 AM mean that carers performed diaper check in other times that are different from scheduled timing.

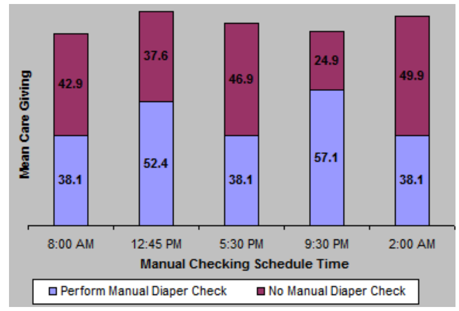

Figure 8. Statistics of Caregiving according to Scheduled Diaper Check

According to Fig. 9, different levels of wetness detection, defined by carers, were recorded by carers during manual diaper check. If the diaper is not completely soiled, they just check the patient's hygiene and put back the original diaper. If the system reports wetness detection, the carer still requires completing the sensor replacement procedure. If the correct procedure is not implied, the sensor may not detect the next wetness episode or may detect the existing wetness state causing false alarm. This practice may affect the credibility of wetness sensor if the sensor placement is right after previously soiled area and it detects wetness right after diaper check.

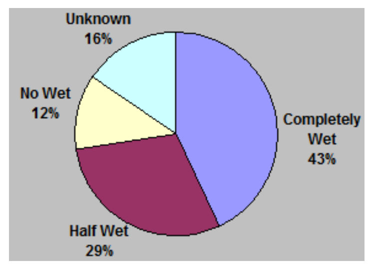

Figure 9. Statistics of Different Degrees of Diaper Wetness States

If wetness occurs after scheduled diaper check, the patient may possibly lie in soiled diapers until the next scheduled check. If there is automated detection of soiled diaper, this can prevent those adverse affects. As seen in Fig. 10, about 52% and 26% of soiled diaper detection from system occurs after and before manual diaper check respectively.

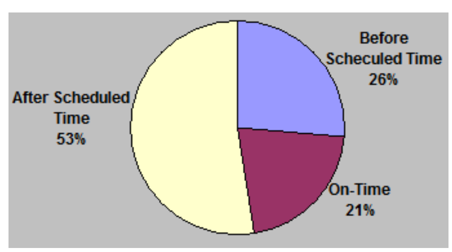

Figure 10. Incidence of Incontinece Episodes according to Scheduled Timing

The definition of on-time, after and before scheduled time is based on time difference of 30 minutes between manual check and system's automated detection. This shows that manual diaper check does not have ability to manage incontinence in a timely fashion in detecting soiled diaper. On the other hand, iCMSv1 enables timely detection, but it misses half of actual wetness occurrences. Also, current wetness sensor replacement procedure introduces discomfort to carers (cleaning and drying the sensor, placing sensor back inside diaper, etc.) and sometimes, system malfunction due to improper handling (sensing surface is not completely dry). So, the most important practical aspect learned is that iCMS should demand minimum amount of involvement from carers, and it should not have complex operation sequences which are difficult to incorporate into a carer's existing work schedule. Moreover, how the carers' interactions with iCMSv1 affect the sensitivity and effectiveness cannot be known due to the lack of usability analysis.

C. *Experiences gained from Trial Operation*

From pilot study with iCMSv1, we realized that the use of pervasive sensor network to observe soiled diapers is feasible especially in infrastructure deployment, scalable monitoring, distributed operation, etc. In order to detect soiled diaper reliably, the optimal location of wetness sensor inside the diaper, front part of diaper, was determined from first few days of trial. The simplicity, user friendliness and intuitive operations also play important roles in proving system to be useful for the clinicians. The bladder charting, ground truth data, recorded by carers include incomplete and sometimes, no information in particular days of the trial. This causes a serious concern in validating the applicability and acceptability of the system using unreliable or inconsistent ground truth data. The requirement of training or coaching carers from nursing home was also observed to let them properly operate the system.

From this trial, we gained insights on how iCMS can be designed and developed to provide desirable assistance to carers. But some parameters are still required to investigate their effects on system performance with multiple patients. According to close observation during trial, PWD may still be out of their bed at least once every morning due to nursing home care requirements. But the wheelchair dedicated to each PWD is used to move them from one place to another. Other experiences include identifying proper means of attaching sensor inside diaper, handling of diaper replacement operation, and providing desirable reminders to notify carers. Moreover, the current procedures and operations to manage incontinence with iCMSv1 impose extra workloads to carer's busy tasks schedule. So, we learned how practical issues related to non-functionality aspects of system such as carers unintentionally throwing away wetness sensor with diaper, without putting sensor inside diaper and placing wetness sensor in wrong orientation or position. Those parameters, somehow, relate strongly to practicality and acceptability of the system.

D. *Drawbacks and Limitiations*

iCMSv1 can reliably observe incontinence episodes while sensing node is located nearby the patient. This scenario causes missing of wetness detection events while sensing node is far from wetness sensor as only single sensing node is used to monitor soiled diaper in both bed and wheelchair. This implies wetness events detected by sensor will be missed when sensing node is not nearby the patient. iCMSv1 requires carers to shift the sensing node according to patient's presence. That results in missing of wetness detection events transmitted by wetness sensor. Improper wetness sensor handling by carers such as sensing surface not dry, etc can result in the system being unable to detect soiled diaper. This problem is due to single wireless transceiver being integrated into WAD to receive wetness events from dedicated sensor. Moreover, it is also unable to monitor the soiled diaper while the PWD is going out of the network coverage with or without sensing node. Also, the monitoring and prompting for incidence of incontinence episodes cannot be performed according to contexts of the patient. As sensor nodes powered by batteries are operating continuously, it raises concerns on problems related to energy efficiency and battery replacement costs in practical use.

In iCMSv1, the management of sensing and reminding operations can only be carried out through WEV at nursing station. So it requires carers to visit nursing station besides diaper change and care giving tasks. This causes operational inefficiency and sometimes WEV is not accessible, resulting in incorrect system operations. Besides technical limitations and operational problems, interactions between carer and iCMSv1 modules can also affect system's performance. Reminders from WEA, light indicators, and WEV did not attract attention from carers due to types of alerts, means of reminding the alerts as well as the condition that carers are far away from reminders. On the other hand, they complained that buzzer alerts cause annoyance to nearby patients. There is also no alert or indicator next to the patient. The carers have to consult with WEV in order to know which PWD has soiled diaper. The user interface design and operation of WEV do not give intuitive feelings to operate. They are also not suitable to manage with multiple PWDs. The logging functionality is available only for system events related to wetness detection and alerts prompting. How the user interacts with WAD, WEA and WEV cannot be analyzed to determine which usability aspect of the system is lacking. Having learned valuable lessons from our experiences with initial pilot study, we are making enhancements and improvements to iCMSv1 in order to eliminate current pitfalls as well as fulfill practical needs to create a new care model for managing incontinence.

VI. ENHANCEMED AND EXTENDED SYSTEM IMPLEMENTATION : ICMSV2

From the experiences and lessons learned from pilot study with iCMSv1 at nursing home, the desirable functional and non-functional requirements can be implemented as iCMSv2. Moreover, usability and evaluation studies with multiple PWD will be conducted at nursing home to validate its effectiveness from considering both technical and clinical aspects.

A. *Usability Study*

As we conducted pilot study with iCMSv1 emphasizing on technical aspects, usability study is planned to understand user reactions to iCMSv2. The acceptance from clinicians is most important to provide assistive solution for managing incontinence. Moreover, operational errors will affect system applicability and undermine the usefulness of iCMS. The status indication of whether the patient is with soiled diaper or not through visual clues and simple push buttons to control system next to the patient will assist carer to be aware and operate it easily. Although the operation guidelines and user manuals of how to manage system are provided, there is still day to day problems pertaining to proper handling of system operations. This can be due to the lack of end-user computer skills, complexity in interaction with system and inherent system limitations related to usability issues. So, all these aspects will be studied thoroughly with iCMSv2 to design user friendly, practical and personalized continence management solution.

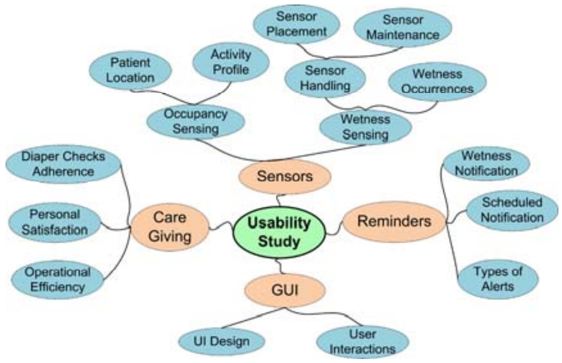

Figure 11. Factors Involved in Usability Study with iCMSv2

As shown in Fig. 11, different aspects of usability issues related to user interaction, reminders, managing sensors and care giving operations will be studied. Moreover, the usability surveys and questionnaires will be conducted to learn the immediate user feedbacks on day to day incontinent care throughout the planned clinical trials. These will be helpful in delivering effective continence management system according to preferences and real necessity from clinicians.

B. System Design & Methodology

From initial trial with iCMSv1, the lack of proper trial protocols and system handling can be observed. For this reason, amendments can be made adding new functionalities as well as defining formal trial protocols and study procedures (Fig. 12) to evaluate effectiveness in managing incontinence with multiple PWDs at nursing homes.

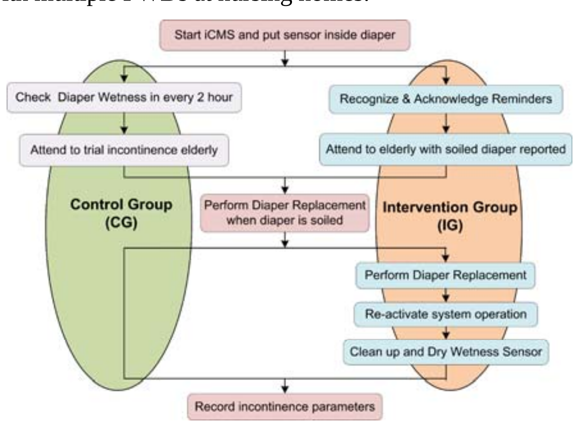

Figure 12. Trial Protocol and Operations with iCMSv2

In order to validate our hypotheses, potential PWD are selected by clinicians according to specific inclusion and exclusion criteria [20]. PWD involved in trials can be divided into intervention and control groups (Fig. 14). Only PWD from intervention groups will be monitored with iCMSv2 whereas both groups are provided the same manual care. Then, PWD from both groups are crossed over to compare how with and without providing iCMSv2 to the same patients result in maintaining desirable level of continence.

C. Extended System Components & Implementation

From understanding limitations and drawbacks of iCMSv1, the functionalities of various hardware and software modules are redesigned and extended to develop iCMSv2. Fig. 13 shows seven main components of iCMSv2 as well as interaction between these components and users.

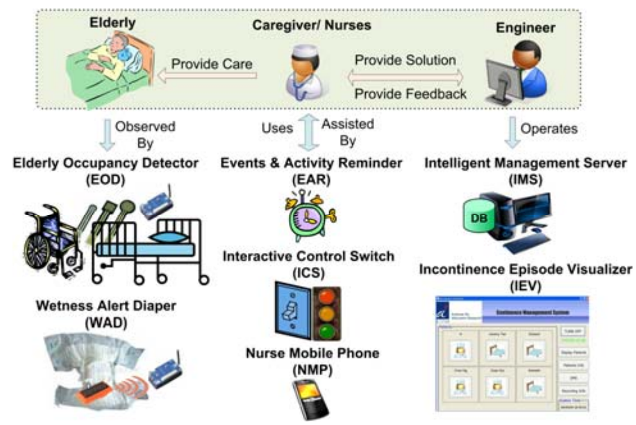

Figure 13. Overview of iCMSv2 Components and Interactions

Firstly, the sensing node is redesigned consisting of Elderly Occupancy Detector (EOD), Interactive Control Switch (ICS) and WAD. It can be classified into mobile and fixed versions attaching to wheelchair and bed respectively. This arrangement works well in our trial of detecting soiled diaper regardless of patient's location because a dedicated wheelchair is assigned to each patient. WAD is also modified by incorporating two wetness transceivers which can communicate with two sensors, and self-contained incontinence detection intelligence. This setting enables the handling of wetness sensor easily and comfortably by carers during diaper replacement. At any particular time, second wetness sensor can be in standby while one is already in use. EOD provides contexts of the patient such as location, presence and activity status. This helps to determine current patient locations and to activate/deactivate the respective sensing node accordingly as part of energy efficiency measures. ICS with push button switch and light indicators is also integrated into sensing node for observing and controlling system operations just next to the patient. This means controlling of continence management operations can be done from either ICS near the patient or Incontinence Episode Visualizer (IEV) at nursing station. This enables observing incontinence status of particular patient effectively, managing system operations intuitively and logging of user interactions with system.

The improvements made into relay/alert node include implementation of robust multi-hops networking and message relaying, and modifying the alerts such as removing light indicator and changing buzzer to melody bell. The prompting of soiled diaper alerts can be delivered to carers through ICS near the patient, Events & Activity Reminder (EAR) through melody bell and Nurse Mobile Phone (NMP) of carers. IEV is completely redesigned and redeveloped to intuitively provide notifications of wetness events, patient's present location and managing particular patient. Lastly, Intelligent Management Server (IMS) supports logging of all system events, user interactions with sensors as well as user interface and user friendly bladder charting application. The following table shows how the improvements made with iCMSv2 meet the limitations and requirements observed with iCMSv1 in pilot study.

TABLE I. iCMSv1 Requirements Vs iCMSv2 Implementation

Problems faced (iCMSv1)	Improvements made (iCMSv2)
Improper wetness sensor handling	Integrating two wetness transceivers to WAD
Placement of sensing node is not in accordance with patient location	Attaching dedicated sensing node to bed and wheelchair
Incontinence episode monitoring is not related to contexts of the patient	Developing EOD using pressure sensing that is integrated into sensing node
Requires energy-efficient sensing node operations	Designing sensing node to activate or deactivate according to EOD
Managing system only from WEV results incorrect system states	Managing system from ICS with simple push button as well as IEV.
Prompting incontinence events from WEA and WEV	Prompting incontinence events from ICS, EAR , IEV and NMP

As shown in Fig. 14, iCMSv2 is deployed at nursing home to cover both mobile and immobile patients. The distributed and multi-hops capability enables monitoring of wetness events anywhere anytime without apparent limitations. In-node intelligence embedded inside sensing node enables energy-efficient sensing, adaptive sampling of sensors as well as location-oriented alerting. If the sensing node is out of sensor network coverage, the detected wetness events cannot reach to IEV and IMS. The self-contained intelligence prompts alerts through ICS and logs detected events to IMS as soon as it returns back to network. This guarantees anywhere anytime observation and logging of incontinence episodes enabling prompt diaper change and reliable system validation.

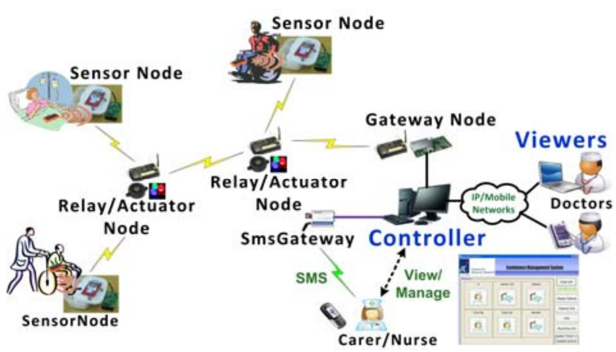

Figure 14. iCMSv2 Deployment Configuration

D. *System Evaluation and Analysis*

With improved features and functionalities of iCMSv2, a series of clinical trials are planned to study the effectiveness of system progressively Multiple PWDs will be recruited with different trial scenarios (Fig. 14) in nursing home to validate our hypotheses and, study iCMSv2 usability and acceptability. The inclusion and exclusion criteria considered in recruiting the subjects involved can be found in Fig. 15 We will also evaluate different reminder types on how they will be useful and the attention received from carers in context-aware, interactive and personalized manner [19].

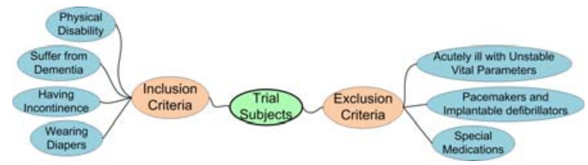

Figure 15. Inclusion and Exclusion Criteria for Subject Recruitments

VII. Discussion: Issues, Challenges and Future Directions

Although iCMSv2 addresses the drawbacks and limitations faced with iCMSv1, there are still open issues and challenges from technical as well as clinical perspectives. A series of clinical trials will be required to be conducted iteratively, making improvements in each step, to eventually reach our goal of promoting quality of care and enhancing quality of life.

A. *Measuring Performance and Clinical Effectiveness*

The challenge we face here is in validating the usefulness of iCMS, the efficiency and effectiveness in managing incontinent patients. From clinical aspects, usefulness and applicability should be measured in two folds. Firstly, iCMS performance on detection of incontinence episodes must closely match with ground truth incontinence profile. The method to determine reliable ground truth in real care settings will still be a challenging issue. On the other hand, the scheduled manual diaper checks cause unnecessary and redundant visits as well as missing actual wetness occurrences. The important point is that evaluation of these factors cannot reliably be done by only considering current measurements and analysis.. From technical side, throughput and reliability of network is an important measure of how the underlying network provides seamless interconnectivity in handling soiled diapers. Moreover, important measure of how iCMS operates energy efficiently for the use of battery-powered wireless nodes is currently lacking. Importantly, several practical usage and unknown non-functional parameters also affect the operations of iCMS that degrade actual effectiveness of the system during trial.

B. *Technical Challenges*

From technical perspective, scalability, number of patients being monitored concurrently, and mobility of those being monitored are requirements that have important ramifications on applicability of iCMS. In order to meet the main objective of the system, every incontinence episode must be detectable anywhere anytime that goes along with elderly for timely diaper change within the nursing home. Although current sensor has small form factor, and wireless connectivity, there is small coverage area and still a burden to carer in its usage. So the desirable features of developing a sensor that is disposable, wireless, has odor detection and film-like form factor design are still a challenging issues. Moreover, the incorporation of monitoring physical and physiological parameters of patients as well as social interactions into sensing node increases difficulties in in-node embedded application development. Due to the involvement of battery-powered wireless sensor nodes with mobility and ad-hoc networking paradigm, the reliability of message exchange, events notification and reminder actuation are apparent challenges faced in real deployment. Moreover, the energy efficient network operation without using battery as well as around the clock monitoring can be considered as important technical issues.

C. Clinical Challenges

From clinical perspective, the ideal wetness detecting sensor should be small in size, disposable and should communicate wirelessly upon detection of either urinary or fecal incontinence. Instead of just reacting promptly after escalation of incontinence episodes, possible proactive measures to incontinent patients can be more desirable. As we have discussed before [19], the simple, easy to use and fail-safe system is desirable as users of iCMS in day to day operations are not very technically oriented. Besides observing wetness episodes continuously, it is desirable to incorporate monitoring of patient's daily profile for trend analysis. Moreover, the indication of whether carers forget to attend patient with soiled diaper or forget to log bladder charting is important to identify possible causes of human errors that degrade effectiveness and usefulness. The carers can unintentionally ignore or can be unaware of reminders that are prompted. So it is important to attract attention from carers in this case through pervasive and intuitive means. Effective continence management requires having prompt attention from carers upon occurrences of incontinence. Moreover, the usability issues related to privacy and acceptability of the system should be studied in depths in future trials. Overall, the desirable features can range from unobtrusive continuous monitoring, odor-based detection, in-situ prompting to personalized assessment and preventive measures such as time voiding, continence planning, etc.

VIII. Conclusion

Effective continence management for PWD requires timely diaper change. Current manual practice demands carers to attend every incontinent patient at specified interval without knowing whether their diaper is soiled. In order to avoid this and enable timely diaper change, a pervasive system with wetness alert diaper is proposed to assist carers to know immediately which elderly has soiled his/her diaper. An initial pilot study was conducted with iCMSv1 evaluating its usefulness, limitations and practical needs. The experiences and lessons learned from evaluation trial were analyzed to design and develop iCMSv2 aiming towards anywhere anytime continence management in nursing homes. We are expecting to provide a new care delivery model, promoting a shift from manual to automated management of incontinence, resulting in enhanced quality of life and quality of nursing care.

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